Using Virtual Reality in the teaching of manufacturing processes with material removal in CNC Machine-Tools

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Introduction

Within the broad field of material forming processes, machining occupies its own merits, a special relevance. The term machining, in the context of manufacturing processes, implies material removal, which means that the final product geometry is achieved by removing material excess from the initial piece or preform. Depending on the physico-chemical method used to produce material removal, the machining processes are varied. For example, chemical milling process uses a chemical attack to the material, wire EDM (Electrical Discharge Machining) uses an electric shock, laser machining uses an electromagnetic beam, ultrasonic machining uses friction between the tool (sonotrode) and the workpiece [1], with endless in the list of processes and alternatives currently used in industry. Taking into account its dissemination, the most relevant process of machining is the conventional machining, the one that supports the removal of material in the relative movement between a tool and a workpiece and in the mechanical interaction generated by the contact between both.

Conventional machining applications are very diverse and cover a broad field, not only about materials but also about geometry and specifications. One consequence arising from the wide dissemination of the machining processes is its continuous improvement. A proof of that is in the constant emergence of new materials or coatings with greater hardness or wear resistance [2], the increase of kinematic and dynamic performance of components for machine tools in which the processes are carried out [3], or the advances in automation [4].

In this latter respect, Computer Numerical Control Machine Tools (CNCMT) are the clearest example. As a result of all this, knowledge and location of CNCMT is very important in engineering education and its study has to be necessarily addressed on both the theoretical and practical if we are to ensure adequate education. Practical use of numerical control machine tools in a learning environment has a number of very significant risks, not only for people but also for the equipments [5]. Recognizing this fact, manufacturers have developed simulation tools that, with varying success, have served to provide the user with visual information of the result of the implementation of a given process. In some cases, these simulation tools are built right into the controls of the machine, which means that their use requires the availability of the machine, preventing it to perform its function. Another alternative offered by manufacturers is simulation programs running on computers, normally personal computers, external to the machine. In this way, the block from the machine during the simulation run is removed. Such programs have a great educational value, but cannot replace the work on the machine itself.

On the idea of bringing simulation to the simulated reality, virtual reality applications appear [6].These applications use a simulation model similar to the previously described applications. However, their great competitive value is that they allow the user to receive sensory information of model behaviour very similar to the sensory information it would receive if working with the real machine. Subsequent paragraphs will make some considerations about practice teaching in the field of CNC Machine Tools, and establish a methodology for the development of virtual reality applications to be used in such education.

Considerations on CNC Machine Tools practice teaching

Apart from the above mentioned drawbacks inherent in the practice teaching of CNC Machine Tool, is complex to establish a line of action without having established four basic parameters, which are: the number of students receiving education, the number of hours available to it, the number of hours of teachers and laboratory staff available and the number and performance of CN equipment. There are other differentiating parameters, such as the level of training required. Throughout this paper it is assumed that the training is aimed at students of engineering, without prejudice to other levels of education to which, in whole or in part, may be applicable considerations and developments raised. In what follows we take as reference the values of the parameters of the ETSI Aeronautics, UPM.

The number of students is approximately 200, which is a highly restrictive condition. For practical teaching to be effective, it requires that the number of students in a working group should be as small as possible, and this requires having to split the group to a high number of subgroups to impart taught separately. At this point comes in the availability of human resources.

At the ETSIA it is established a number of subgroups with a size between 10 and 12 students as the necessary human resources for this is available, consisting of two teachers and two people of laboratory staff who manage with the equipments. Each group receives 8 hours of practical training in which they are talked about the main characteristics of CNC Machine Tools (lathe and milling machine). A practical application as a demonstration is carried out in both of them and finally, the students split into teams of two or three members, develop a comprehensive process of machining, from the design of the piece to its full production in the machine.

For this task there are two training machines, whose special characteristics enable them work on minimizing the risks of use. To ensure that all activities take place within the time available without generating extra work outside the laboratory, it is necessary to simplify certain actions that could develop if it were available a sufficient number of CNCMT.

Since this option represents a considerable investment, the creation of virtual reality based CNC Machines offers a viable alternative within a reasonable cost, and opens new possibilities that allow the use of equipment with different benefits. Some of the machine tools used in the development of practical classes appear in Fig. 1.

Fig. 1. Numerical Control Machine Tools

Methodology for developing a Virtual Reality application

The followed methodology for the development of a Virtual Reality application is described schematically in Fig. 2. For application and obtaining a successful outcome, one must begin with knowledge of the machining process as detailed as possible. This fact makes it essential the participation in the development of "experts in manufacturing processes" having such knowledge, whether or not possessing knowledge of simulation or Virtual Reality. At the level of abstraction one creates the simulation model and defines what elements and behaviours must be considered and to what level of detail should be modelled. This level presents an intrinsic difficulty by simultaneously requiring deep understanding of the processes to model and software tools to use, circumstances that are not always satisfied in the same person [7].

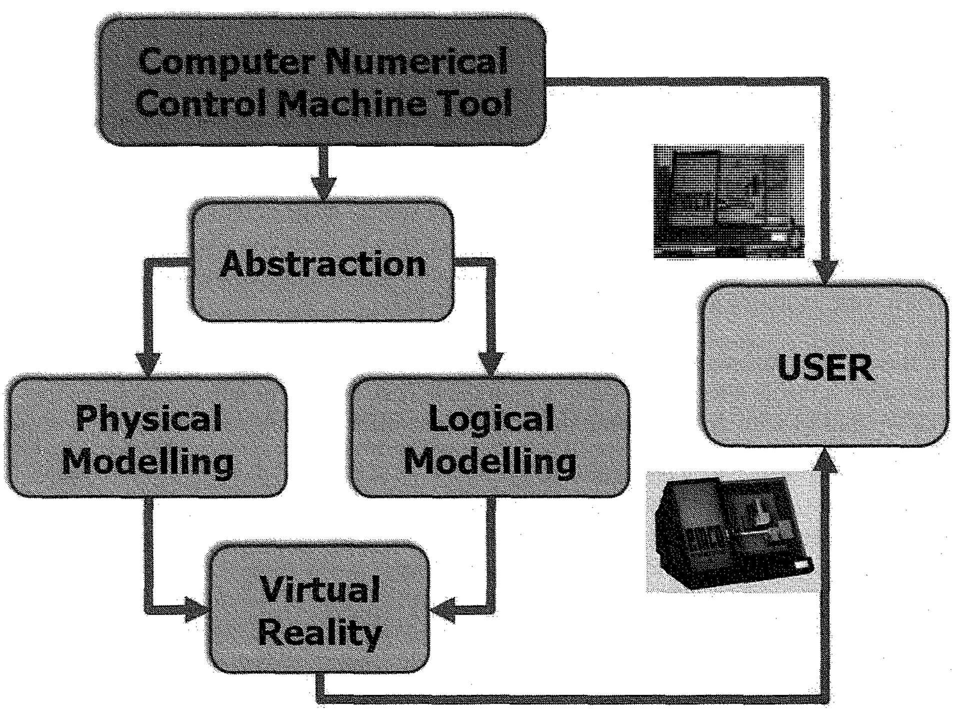


Fig. 2. Virtual reality outline

The level of modelling includes both the "physical" and the "logic" part of the elements involved in the model. The physical modelling considers the whole physical properties that characterize each element of the application. It primarily focuses on geometric properties (dimensions and shape) of the element that will affect their interaction with other elements of the application. Specific applications of 3D modelling can be used for this modelling. They are currently available on the market at affordable costs. On the other hand, the logic modelling attempts to establish rules of behaviour that determine the interaction between the different elements. For this modelling, there are specific applications whose number is very small compared with those available in the physical modelling. Finally, Virtual Reality level, provides the user interface. The software to use depends on the available hardware, which can range from a simple personal computer to a virtual immersion room. It is desirable to use software with good performance and a wide range of connectivity hardware devices [8].

Abstraction of a CNC Machining Tool

A CNC Machining Tool could be defined as a set of mechanical, electrical, hydraulic and / or pneumatic that by working together and through the action of a control unit that processes information numerically encoded, allow the relative motion between the workpiece and the tool and the removal of excess material from the starting preform. There is great diversity of CNCMT with different features in terms of powers or degrees of freedom of movement. Fig. 1 shows some of the CNCMT available in the Laboratory of Manufacturing and Production Organization of the ETSIA-UPM.

Within this great diversity, drilling and milling machines are the most common types. To make the abstraction of a CNCMT it is needed to think about the essence of its operation, and this essence derives precisely from the fundamental concept of machining: the relative motion piece-tool, which allows the removal of excess material from the starting preform. In a first approximation, from the point of view of abstraction, how to generate the movement is not a relevant issue. What really matters is the existence of this movement and its basic kinematic characteristics, their nature and the range of velocities and accelerations admissible. Thus the CNCMT may be initially abstracted as a set of movements that can be applied simultaneously on a given point [9]. Each of these movements are accomplished by the action of a drive, which is the basic element of abstraction of a CNCMT.

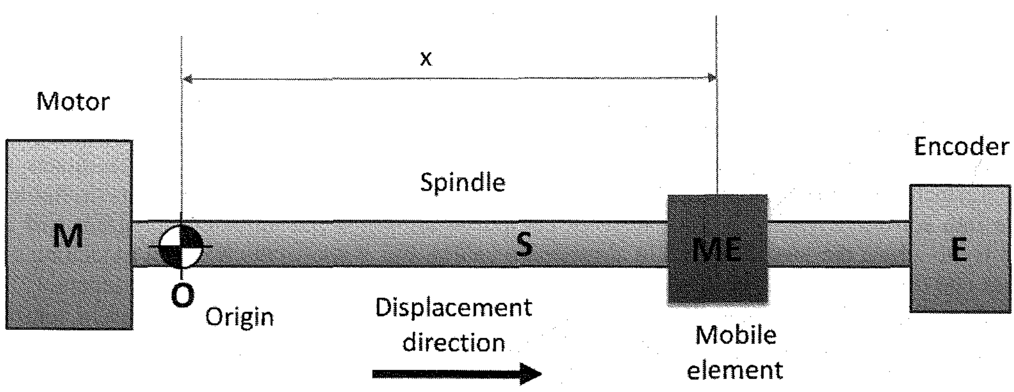


Fig. 3. Drive outline

A drive can be sketched as shown in Fig. 3. It consists of a propellant or motor (M) that rotates a spindle (S) on moving a mobile element (ME). The position of the mobile element is fixed by the value of a scalar x, measured from the origin (O) in the direction of movement. The position record is made by the register or encoder (E). The diagram in Figure 3 corresponds to a linear drive. In the case of an angle drive, the basics are the same, except that the scale represents an angular value rather than a dimensional value and the displacement of the mobile element is a rotation rather than translation. This drive concept can be applied to each and every one of the moving parts of CNCMT elements, while not directly related to the relative motion between workpiece and tool. For example, a fixture as it can be a plate or jaw, or an element of protection as the gateway to the work area can also be initially abstracted from the drive concept presented.

Physical Modelling

Once raised the abstraction of the CNCMT, it means, once defined the constituent drives and the parameters that characterize each of them, the next step is to physically model moving elements. This requires creating three-dimensional models (3D objects) to represent the geometry of the real elements in the virtual world. The level of detail of 3D objects is a very important parameter to consider. If you want the physical model of a particular element to present a high degree of realism, this implies that the geometric model of this element will require a large number of areas (polygons).

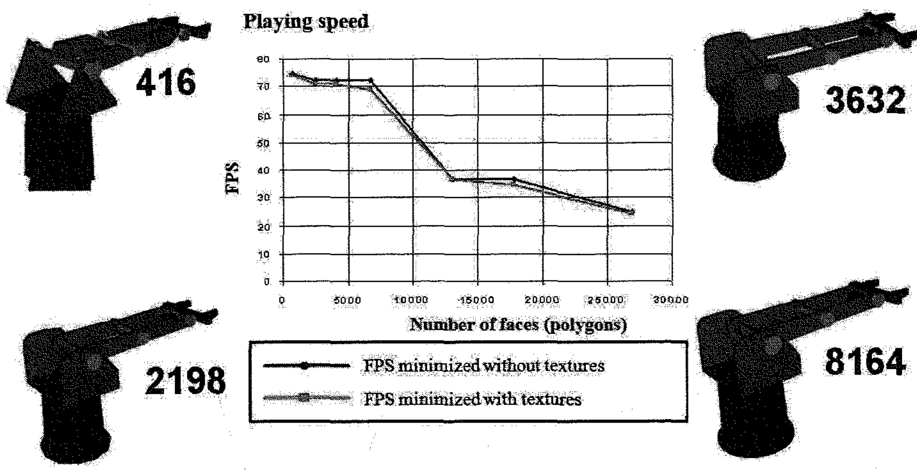


Fig. 4. Number of faces (polygons) vs. visualization speed (FPS)

When the number of polygons and the number of modelled elements grown, the volume of information to be handled by the simulation program can exceed the performance of the computer on which it runs, making the presentation of the results with the minimal realism required impossible. In this sense, the performances of computers advance so fast that facilitates the management of information amounts a few years ago were unthinkable. However, it is desirable to take into consideration the performances of computers on which the simulation program will run and try to adjust the level of detail to appropriate values. Fig. 4 shows the physical modelling of a robot and the variation of the speed of visual representation, expressed in frames per second (FPS) based on the number of polygons used in the three-dimensional model. Another aspect to consider in physical modelling is the definition of assembly points of different 3D objects and scales.

Indeed, each 3D object can be modelled independently, but in the end all items must be assembled. This assembly should be done in a very precise way, as in the reality of a CNCMT, the assembly of the mechanical elements that compose it is essential for its proper functioning. In this way, is very appropriate the definition of objects which do not have associated geometry, but simply represent a location and an orientation. Such objects are called frames, and its definition greatly facilitates assembly and replacement models for others within the same set. A final aspect of physical modelling has to do with the need to establish hierarchies among the different three-dimensional models that are the CNCMT. Indeed, if a fixture as a gag rests on a milling table, table movements affect the jaw, which means that it is necessary to establish a link between certain objects in order to consider this issue. This relationship is done by establishing hierarchies parent-child "between the different graphic objects so that all movements that affect a specific object, also affect all objects with a hierarchy of "child". Fig. 5 shows the hierarchy for a numerical control drilling machine.

Logical Modelling

Logical modelling provides the behaviour of components of the virtual model. For this modelling is desirable to establish a separation between two sublevels, the first of them corresponding to the behaviour of 3D objects in the virtual environment and the second concerned with control of CNCMT behaviour.

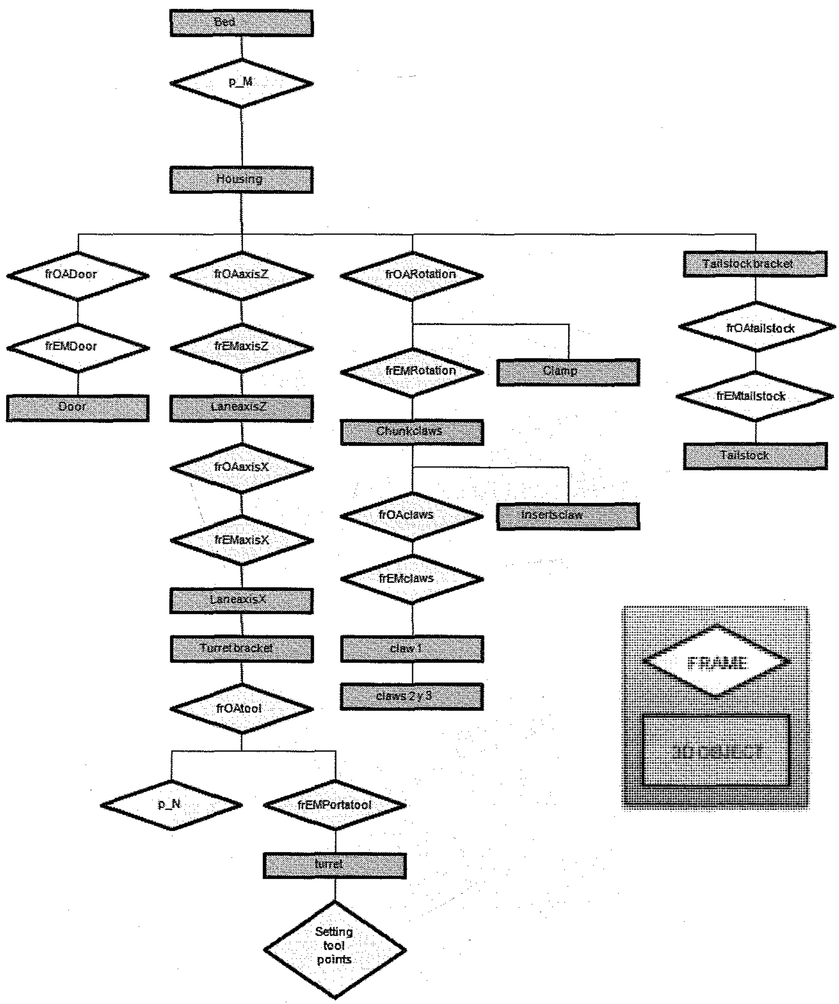
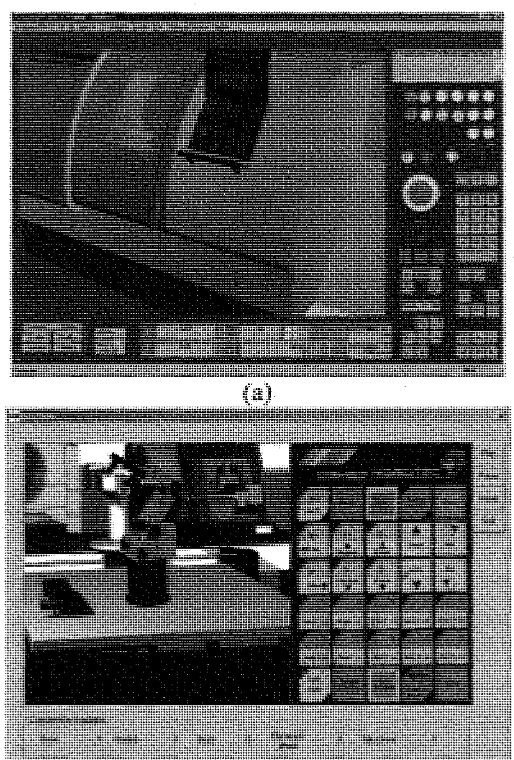


Fig. 5. 3D Objects hierarchy on a CNCMT

Logic modelling of action. 3D objects have a number of properties that determine their behaviour in a virtual environment. For example, its geometry defines a spatial area that cannot be occupied simultaneously by other 3D objects, as this would be an interpenetration that does not correspond with reality. All these behaviours related to physical properties of 3D objects can be approached from an object-oriented programming and in fact there are programs for this purpose. Specifically, the application [10] meets this requirement in addition to other duties.

Logic modelling of control. This sublevel takes into account the performance criteria that determine the behaviour of 3D objects. Basically this sublevel is identified with the CNCMT control and its implementation is done through a language of object-oriented programming.

Virtual Reality. The last step of the methodology is the development of virtual reality application itself. This requires assembling all the models generated, establishing hierarchies, modelling the behaviour of acting, modelling the behaviour of control and establish the communication interfaces between the different levels. The final result creates an application that interacts with the user and, ideally, provides a sensory stimulation equivalent to that of the equipment simulated. In practice, this stimulation is focused on the visual sense, since most of the sensory information received by humans comes from the sense of sight. However, depending on the hardware available, there are devices to interact with other senses, especially hearing and touch. However, this type of devices has not yet a comparable degree of availability as visual devices, despite the significant advances in recent years. The aspect that may have an application developed with low cost material resources would be the one shown in Fig. 6.



(a)

(b)

Fig. 6. Virtual Reality developments for CNCMT: (a) CNC Lathe (b) Robot

Conclusions

Learning the workings of the Computer Numerical Control Machine Tools (CNCMT) is of significant importance to the engineer in the field of material forming processes. The nature of the equipment and processes makes practical training in this area necessary. The costs of CNCMT and the operating conditions impede practical learning, because it cannot be left in the hands of "amateurs", and by nature learners are so, the use of equipment that could endanger the integrity of people and machines. Virtual reality helps to minimize these risks, and expand the field of computers on which you can practice without any physical risk. The development of a virtual reality application is complex, so it needs a sufficiently clearly established methodology for their implementation. In this paper we present the main guidelines to follow to create an application based on virtual reality. Practical results of proposed methodology have led to excellent learning outcomes as has been contrasted with the scores of students of the School-UPM for the past five years, although there is still a long way to go in Virtual Reality teaching develop.

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